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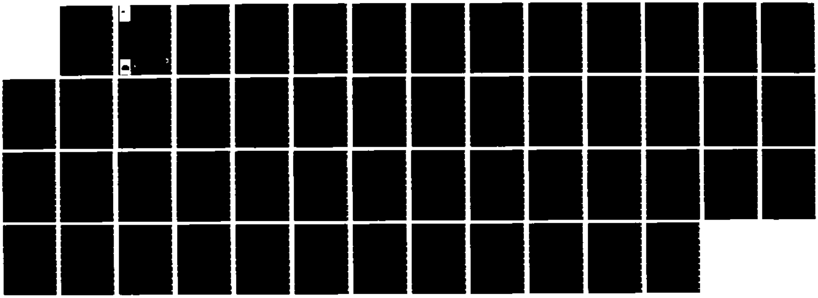

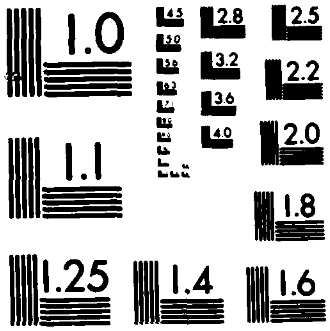
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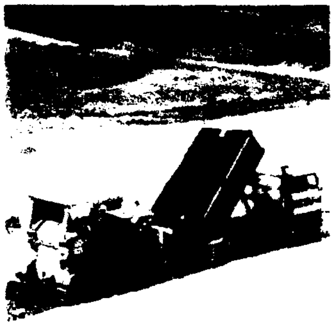

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SOIL-CEMENT STUDY, TRUSCOTT BRINE DAM, TEXAS

by

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Fly ash, frost damage tests, high sulfate and chloride contents in reservoir, physical properties, slope protection, soil-cement, sulfate resistance, Type II and Type V cements, wetting-drying tests

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Soil-cement was considered as a slope protection material to be used on the Truscott Dam which will impound water having high sulfate and chloride contents (3,000 mg/L and 10,000 mg/L, respectively). Type II and Type V cements, with and without fly ash as a cement replacement, were used to prepare specimens for the following tests; compressive strength, sulfate attack and expansion, wetting-drying, frost damage, and optimum moisture-maximum density. It was recommended that a mixture of 10 percent Type V cement and a granular non-plastic soil be used to provide the required slope protection.

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PREFACE

This research program was authorized by DA Form 2544 Number TNT 78-22, dated 12 April 1978, with change order number 1, dated 7 May 1979. It was conducted by the Structures Laboratory of the U.S. Army Engineer Waterways Experiment Station (WES) and was sponsored by the Foundations and Materials Branch, U. S. Army Engineer District, Tulsa. Funds for publication were provided by the Concrete Technology Information Analysis Center (CTIAC) under CTIAC Number 75. The work was accomplished under the general supervision of Messrs. Bryant Mather, Chief, Structures Laboratory; J. M. Scanlon, Chief, Concrete Technology Division; and G. C. Hoff, Chief, Materials and Concrete Analysis Group. Other staff members actively participating in the investigation were Messrs. Robert H. Denson, Tony Husbands, and Olen K. Loyd.

The study was coordinated with Messrs. Glenn Bayless, Chief, F&M Branch, and Carl Davis, Tulsa District.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
gallons (U. S. liquid)	3.785412	litres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
pounds (mass)	0.4535924	kilograms
tons (2000 pounds mass)	907.1847	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic yard	0.59327638	kilograms per cubic metre
pounds (force) per square inch	0.006894757	megapascals
miles (statute)	1.6093	kilometres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[a]
BTU-ft/hr-ft^2-°F	0.01201899	W/(m·K)
ft^2/hr	0.0000258064	m^2/sec

[a] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

SOIL - CEMENT STUDY
TRUSCOTT BRINE DAM, TEXAS

PART I: INTRODUCTION

Background

1. The Truscott Dam was designed to impound water containing large amounts of sulfates and chlorides with the initial concentrations estimated as being 3000 mg/L and 10,000 mg/L, respectively. The ultimate concentrations of sulfates and chlorides in the water were estimated to be 6,000 mg/L and 56,000 mg/L, respectively. The soil-cement will be used for upstream slope protection and will be produced using water containing large amounts of sulfates and chlorides, the amounts being less than those of the impounded water.

Objective

2. The principal objective was to determine the best soil-cement mixture proportion to be recommended for use on the project. The test program consisted of producing soil-cement mixtures with varying levels of cement content, using Types II and V cement, and by varying the amount of fly ash as a cement replacement.

Approach

3. The research program was accomplished by establishing the physical properties of the soil intended for project construction, by varying the percentages of Type II and Type V cement, and by comparing the mixtures containing various amounts of fly ash. Once the soil-cement mixtures had been proportioned and cured, samples of each were subjected to freezing and thawing, wetting and drying, sulfate attack, compressive strength, and ultrasonic pulse velocity tests.

PART II: DESCRIPTION OF COMPONENT MATERIALS

Components

4. The component materials of the mixtures investigated were Types II and V cement, sandy soil, fly ash and water.

Cement

5. Types II and V cements were used in the investigation because of their ability to withstand certain levels of sulfate attack. Typical chemical and physical analyses for Types II and V used in this study are shown in Table 1.

Fly ash

6. Two series of mixture proportions contained a 20 percent replacement (by weight) of Class F fly ash to measure its effect on parameters such as cost reduction, strength gain and resistance to sulfate attack. The typical physical and chemical analysis of the fly ash used in this investigation is shown in Table 2.

Soil

7. The physical properties of the soil were established by performing gradation, hydrometer analysis, and Atterberg limit tests as described in Engineering Manual EM 1110-2-1906, "Laboratory Soils Test" (30 Nov 70). Figure 1 contains the sieve and hydrometer analyses of the soil and Table 3 is the gradation curve. The material is described as a non-plastic reddish brown silty sand (SM).

8. The soil was further characterized by x-ray diffraction which established the mineralogical composition. A small representative sample was obtained from the sample submitted by the U.S. Army Engineer District, Tulsa. A portion of this was ground to pass a 45-μm sieve (No. 325) and examined by x-ray diffraction; another portion of the ground sample was mixed with water and dried on glass slides. The resulting films were examined by x-ray diffraction; the sample was in the air-dry state after treatment with glycerol, and after heating to 350°C for one hour. The x-ray patterns were made with an x-ray diffractometer using nickel-filtered copper radiation.

9. The material was a reddish, iron stained, calcareous, and sandy soil which contained a trace of clay. Its approximate composition is shown in Table 4.

10. The chemical composition of the soil was determined by a chemical analysis. Approximately 50g of the soil was ground to pass a 75-μm sieve (No. 200) and dried at 105°C. Small portions of the ground soil (0.5g) were fused with lithium metaborate and the fusion dissolved in 1:3 nitric acid. The solution was then analyzed by an atomic absorption spectrophotometer. The chemical composition of the soil is shown in Table 5.

Mix water

11. A 5 gal sample of tap water from Truscott, Texas was provided by the Tulsa District for use as mix water in the investigation. The water was analyzed and the results are shown in Table 6. Large quantities of the Truscott tap water could not be obtained for making the soil-cement specimens, therefore, the water was prepared in the laboratory. Reagent grade chemicals were dissolved in distilled water to obtain a water very similar in composition to the Truscott tap water. Table 7 shows the composition of the laboratory water.

Project water

12. The initial concentration of sulfates and chlorides from the water sources which will be flowing into the Truscott dam will be 3000 mg/L and 10,000 mg/L respectively. It was predicted that the ultimate concentration of sulfates and chlorides in the water would be 6,000 mg/L and 56,000 mg/L respectively, based on the volume of water impounded, evaporation, and the solubility of the salts in the brine water.

13. Two samples of water, one from Bateman and one from North Wichita River, two of the water sources that will be flowing into Truscott Dam, were obtained from the Tulsa District. These two samples were analyzed and the results are shown in Table 9. The remainder of the two samples were then poured into plastic trays. The trays were set in laboratory air so that the water would evaporate at a slow rate. Small aliquots from the two water samples in the trays were analyzed at various intervals until the chloride content of each water had obtained a concentration of approximately 56,000 mg/L. The water samples were then analyzed and the results are shown in Table 10.

14. The sample from Bateman had a sulfate content of 6,240 mg/L after evaporation which was about the same as the predicted sulfate concentration (6,000 mg/L). However, the sample from North Wichita River had a sulfate content of 8,910 mg/L after evaporation. The difference in the sulfate contents of the two water samples is mostly likely attributed to the different types of sulfate salts dissolved in the waters. The average sulfate content of the two samples was 7,580 mg/L. Based on these results the project water was made to contain 7,500 mg/L sulfates. The project water was made by dissolving 90.66g NaCl, 13.17g $MgSO_4 \cdot 7H_2O$ and 4.30g $CaSO_4 \cdot 2H_2O$ in 1 liter of distilled water. Therefore, the project water contained the concentration of ions as shown in Table 8.

PART III: LABORATORY TEST PROCEDURES AND OPTIMUM MOISTURE - MAXIMUM DENSITY VALUES

Variations of parameters

15. A test program was designed to identify and establish the physical properties and response levels of several soil-cement mixtures by the following combinations of materials.

- a. Type II cement at 6, 8, 10, 12, 14, and 16 percent cement content.

- b. Type II cement with 20 percent fly ash replacement of cement and cementitious material contents of 10, 12, 14, and 16 percent.

- c. Type V cement at 10, 12, 14, and 16 percent cement content.

- d. Type V cement with 20 percent fly ash replacement of cement and cementitious material contents of 10, 14, and 16 percent.

Description of tests

16. The following paragraphs describe the various tests that were preformed to define or characterize the component materials, prepare the samples, and measure their response to the tests. All tests results are given in PART IV: TEST RESULTS, of this report.

Compressive strength

17. Compressive strength values for the mixtures were established according to the method as described in CRD-C 14-80[1] "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." The test specimens were 4-in. diameter by 4-in. high and were prepared, at the maximum density - optimum moisture value, using the method and equipment as given in CRD-C 592.

Standard wetting-and-drying

18. Wetting-and-drying specimens were prepared as described in CRD-C 592 and were tested in accordance with the provisions of CRD-C 573-74[1] "Standard Methods for Wetting-and-Drying Tests of Compacted Soil-Cement Mixtures."

Freezing-and-thawing

19. Freezing-and-thawing specimens were prepared as described in CRD-C 592 and were tested in accordance with the provisions of CRD-C 594-74[1] "Standard Methods for Freezing-and-Thawing Tests of Soil-Cement Mixtures."

Sulfate attack (immersed)

20. Specimens for the immersed sulfate attack tests were prepared, at the optimum moisture-maximum density value for each mixture, as described in CRD-C 592. The specimens were cured in the fog room for 28 days, then weighed and measured. Stainless steel length-measurement inserts were then placed in

holes drilled at the center of each end of the specimens and cemented with epoxy. After initial length measurements were made the specimens were immersed in the project water containing 7,500 mg/L sulfates and 55,000 mg/L chlorides as described in paragraph 14. The specimens were periodically measured to produce a time-functional length-change history.

Sulfate attack (cyclic wetting-and-drying)

21. Specimens for the cyclic wetting-and-drying sulfate attack tests were prepared, at the optimum moisture-maximum density values of each mixture, as described in CRD-C 592. The specimens were cured in the fog room for 28 days, then weighed and measured. Stainless steel inserts were then placed in the specimens as described in paragraph 20. After initial length measurements were made, the specimens were placed in pans containing project water in a manner such that the water was approximately 1/2-in. high on the sides of the specimens. One complete cycle of wetting-and-drying consisted of the specimens soaking in the 1/2-in. depth of project water for 8 hr then being dried for 16 hr at 160°F. The specimens were periodically measured to produce a time-functional length-change history.

Ultrasonic pulse velocity

22. Ultrasonic pulse velocity tests were performed on certain specimens according to the provisions of CRD-C 51-72[1], "Standard Method of Test for Pulse Velocity Through Concrete."

Optimum moisture - maximum density values

23. Optimum moisture - maximum density relationships of the mixtures were established according to the provisions of CRD-C 592-74[1] "Standard Methods of Test for Moisture Relations of Soil-Cement Mixtures." Table 11 gives these values for the soil-cement mixtures investigated. Figures 2 through 11 are the curves for these mixtures.

PART IV: TEST RESULTS

Test Data - 28 day cure phase

24. One group of specimens was cured in the fog room for 28 days at 97 percent relative humidity and 73°F. They were then removed from the fog room and subjected to the following tests with the indicated results.

a. Compressive strength. These tests reveal that the mixture containing 16 percent Type II cement, with no fly ash, attained the highest strength, 2510 psi. However, assuming that 700 psi is the acceptable minimum strength required, all mixtures except the 6 and 8 percent Type II mixtures attained acceptable strengths. Table 12 gives the data for this test.

b. Freeze-thaw. These specimens were removed from the fog room at 28 days and were subjected to 45 cycles of freezing and thawing. The mixture containing 16 percent Type V cement with no fly ash exhibited the highest resistance to frost damage (1.2% loss by weight) and the mixture containing 10 percent Type II with 20 percent fly ash offered the least resistance (26.1% loss by weight). Table 13 shows the percent loss for each mixture tested.

c. Standard wetting-drying. This test was performed by using specimens that were cured in the fog room for 28 days and then subjecting them to 45 cycles of wetting and drying, as described in the test method shown (paragraph 18). The data from this test is an indicator of the resistance to the effects of alternate wetting and drying, caused by waves in the splash zone of the upstream face of the slope. However, for this standard test, local tap water was used in place of the project water. The least resistant was 10% Type II with 20 percent fly ash. Table 14 gives the data from this test.

d. Resistance to cyclic wetting and drying sulfate attack. The specimens for the first phase of this program (Types II and V, with and without fly ash, 10-16%) were processed differently from those of the second phase (Type II and V, without fly ash, 6 and 8%). Therefore, the data of these two phases is presented separately and must be evaluated accordingly. The first phase specimens were cured in the fog room for 45 days and then tested. The times shown in Table 15 are days after initial 45-day cure. The expansions shown, unless stated otherwise, reflect that change in the wet state. The values have been rounded to the nearest 0.01 percent.

The second phase specimens were cured in the fog room for 28 days and then tested. Table 16 presents this data. The values have been rounded to the nearest 0.01 percent.

e. Resistance to constant sulfate attack (immersed condition). The specimens, for both phases, in this test were cured in the same manner as described in paragraph 24d. All specimens, after the test began, remained immersed and were removed only for length-change measurements. Tables 17 and 18 give the resulting data from these tests.

f. Ultrasonic pulse velocities. The ultrasonic pulse velocity was measured on representative samples from each condition (cement type and percent, percent of fly ash) and according to type of sulfate attack (wet-dry cyclic and immersed). However, the 6 and 8 percent - Type II samples were measured initially only after 28 days cure in the fog room. All others were measured after 28 days fog room cure and at the intervals shown. Tables 19, 20, and 21 give these data. All specimens were measured in the damp or wet state.

Test Data - 28 day
+ 6 month cure phase

25. One group of specimens was cured for 28 days in the fog room and then was buried in dry sand at room temperature for 6 months. At the end of the curing period the specimens were then subjected to the different conditions and tests as described.

a. Compressive strengths. Once the curing period ended some of the specimens representing each category were tested for compressive strength and are reported in Table 22. The values listed are the averages of three specimens.

b. Freeze-thaw. One group of specimens was subjected to 21 cycles of freezing and thawing and the weight loss measured and recorded. Table 23 is the record of this data.

c. Standard wetting and drying. The standard wetting-drying test was performed on one group of specimens at the end of the 28-day plus 6-month cure period. The initial and final weight measurements were made while the specimens were in the damp condition; therefore the slight gain shown is due to the influence of the level of moisture present. However, this also indicates there is no deterioration caused by the cyclic wetting and drying. This is confirmed by the very slight percentage of loss indicated on some of the specimens. Table 24 lists the data for this test.

d. Resistance to cyclic wetting and drying sulfate attack. After the curing period ended, a group of specimens was subjected to the cyclic wetting-drying effects of the project water. Expansions at 7- and 14-day intervals were measured at the end of the wet cycle whereas the 180-day measurements were made when the specimens were dry. Table 25 reports the data for this test.

e. Resistance to sulfate attack (immersed condition). These specimens, at the end of the curing period, were immersed in project water and were removed only for length measurements. The length changes are recorded in Table 26. All measurements were made in the damp condition and the values reported are the average of three values for each data point.

f. Ultrasonic pulse velocities. The ultrasonic pulse velocities were measured at the end of the 28-day + 6-month cure period. These measurements were made prior to any testing on these specimens and therefore reflects the condition or soundness of the material in the relatively undisturbed state. This data is recorded in Table 27.

Test data - 7-day +
1-day accelerated cure phase

26. One phase of the test program consisted of subjecting the specimens to 7 days cure in the fog room then placing the specimens in plastic bags and immersing them in water for 24 hr at a temperature of 130°F. The specimens were then tested in the following modes.

a. Compressive strength. Table 28 gives the 8-day compressive strengths of some specimens after the accelerated cure period.

b. Resistance to freezing and thawing. Table 29 gives the data for the freeze-thaw test performed on a group of specimens cured for 7-days in the fog room and 24 hours at 130°F. There were 15 cycles of freeze-thaw.

c. Standard wetting and drying. Table 30 gives the results of subjecting one group of specimens to 14 cycles of standard wetting and drying at the end of the 7-day + 24-hr cure period.

PART V: DISCUSSION, CONCLUSIONS, RECOMMENDATIONS

28-day cure phase

27. There appears to be a 4 to 8 percent increase in compressive strength by omitting the addition of fly ash in the Type II cement whereas this same omission produces a 33 to 47 percent increase with the Type V cement. A comparison of the two cements reveals an increase of compressive strength of 2 to 9 percent by using Type II cement as opposed to Type V (with no fly ash) and an increase of 20 to 48 percent using Type II versus Type V (with fly ash). Neither the 6 nor 8 percent Type II produced a minimum compressive strength of 700 psi (345 and 540 psi).

28. In the range of 10 to 16 percent cement content, Type V exhibited only one-half the weight loss of Type II (neither with fly ash) when subjected to freeze-thaw cycling. With the addition of fly ash to both cements, Type V showed a one-third weight loss compared to that of Type II. There was a considerable reduction of weight loss in both types with the increase of cement content. Conversely, the addition of fly ash tended to diminish the resistance of each cement to frost damage when compared to the "cement only" mode. However, in the 6 and 8 percent range (Type II) the weight losses were 2.4 and 5.5 percent.

29. Both cement types exhibited an increase in resistance to the effects of cyclic wetting and drying as the cement content increased and an even greater resistance by the addition of fly ash. There was only a slight insignificant enhancement of resistance by Type V over Type II.

30. There seems to be very little difference between the performances of the two types of cement, with and without fly ash, in resisting volume changes caused by salt crystal growth. However, the data shows that resistance increases with an increase in cement and cementitious material contents. Neither the presence or absence of fly ash nor the type of cement used appeared to significantly contribute to the enhancement of the resistance to expansion. The measured expansion did not, of itself, appear to adversely affect the integrity of the soil-cement. The expansion was approximately the same in the cyclic wetting-drying mode as it was in the totally immersed mode.

31. The soundness of the soil-cement, as evidenced by the ultrasonic pulse velocities, was affected more by the presence of fly ash than it was by the type of cement. The impulse traveled faster through the fly ash mixtures than it did through corresponding cement-only mixtures. There was a corresponding increase in velocities with increases in cement and cementitious material contents.

28-day + 6-month cure phase

32. The compressive strengths of the Type II cement mixtures were slightly higher than those of the Type V; however, the presence of fly ash in both types reduced the compressive strengths. Type II with fly ash showed a slight net loss of weight from the effects of the standard wetting-drying test, whereas the other three conditions (Type II w/o fly ash and Type V w and

w/o fly ash) showed a slight net gain in weight due to the presence of moisture. There were no real differences among all the conditions in their abilities to withstand the expansive effects of the cyclic wetting-drying sulfate attack test. This was also the case in the totally immersed sulfate attack test. The ultrasonic pulse velocities where slightly higher, in both types of cement, with both the increase in cement content and with the absence of fly ash.

7-day + 1-day accelerated cure phase

33. The compressive strengths, using both types of cement, increased with increases in cement and cementitious material contents; however, there were no real differences in the strengths when comparing mixtures containing fly ash with those with no fly ash. The Type II mixtures exhibited a slightly greater resistance to freeze-thaw mechanism with no real differences noted by the presence or absence of fly. All four conditions exhibited equal resistance to the effects of the standard wetting and drying test.

Effects of length and type of cure

34. The additional 6 months curing period made the greatest impact on the compressive strength. The compressive strengths of the longer period were greater than the 28-day by an average factor of 1.90 whereas the strengths of the accelerated cure specimens were only 0.70 that of the 28-day strengths. The increase in strength was caused by the contribution of the cementitious properties of the fly ash, which usually requires approximately 90 days to develop, and the more complete hydration of the cement.

35. Frost attack (freeze-thaw) caused less deterioration to the "longer-cured" specimens than to the other two phases, with the 28-day group responding only very slightly better than the accelerated group. In general the fly ash mixtures offered less resistance than the non fly ash group and Type II resistance was slightly less than Type V.

36. The standard wetting-drying test reflected the impact of the additional cure time in that several of the specimens had a net gain in weight. The slight deterioration of the specimens was offset by a gain in moisture weight which resulted in a net gain. There was very little difference in response between the other two phases.

37. The additional cure time greatly enhanced the resistance of the soil-cement to the expansive effects of salt crystals growth in the cyclic wetting-drying sulfate attack mode. The 28 day specimens expanded, by a factor of 3 to 4, more than did the 28-day + 6-month specimens. However, the expansion rate of the totally immersed specimens was approximately the same for both cure periods. It appears that the increase in the compressive strength (and therefore an increase in tensile strength) caused by longer cure time enhanced the ability of the material to resist the expansive forces in the cyclic mode.

38. There is an indirect relationship of soundness between the two types of sulfate attack, at the shorter cure time, and the undisturbed state at the longer cure time. The ultrasonic pulse velocities were approximately the same

for both cure times even though the shorter-cured specimens had been subjected to sulfate attack. It appears that the material is not adversely affected by sulfate attack because the velocity values are rather high for both cases.

Conclusions and Recommendations

39. As stated in the objective paragraph of this report, a determination would be made as to the best soil-cement mixture to use on the field project. It was implied that the best mixture would be the one that would be cost-effective while at the same time successfully withstanding the different attack modes imposed. It was also agreed that the minimum compressive strength would be 700 psi in 28 days and the material would be required to be compacted to 95 percent maximum density. The 6 and 8 percent cement content (Type II) mixtures do not produce the minimum required compressive strength and are therefore unacceptable. All other mixture proportions exceed the minimum value.

40. The most severe type of attack was the freeze-thaw mechanism. The mixtures with no fly ash offered more resistance than those containing fly ash and the Type V offered more resistance than did Type II. The data also shows that the longer cure times increase the resistance to frost damage. These same generalizations apply to the mixtures in offering resistance to the standard wetting and drying attacks.

41. The mixtures were more affected by the length of the cure period with both types of cement, then by the type of cement in both modes of sulfate attack. Therefore, the type of cement chosen will be a matter of choosing the cheaper of the two and then assuring that a proper cure time and method are employed during construction.

42. Both types of cement, with and without fly ash, exhibit high soundness values which indicates that the cheaper cement, with a fly ash replacement and a 10 percent cementitious material content, would adequately meet design requirements.

43. It is recommended, therefore, based mainly on resistance to frost damage (the most adverse mode), that a soil-cement composed of 10 percent Type V cement, with no fly ash, and a granular nonplastic soil will offer the best cost-effective material system for meeting the basic job requirements. However, Type II cement, in the same proportions as just stated, shows only approximately a 3 percent greater loss and a cost-engineering decision must be made to justify the greater cost of using Type V cement.

44. It must be recognized by all concerned that the soil used in this test program was a granular non-plastic soil (sand) and therefore this data cannot be assumed to apply to any other soil type. It is further recognized that should other job requirements be added in the future, the data must be reevaluated to reach proper conclusions and recommendations to account for these new requirements.

REFERENCE

U.S. Army Engineer Waterways Experiment Station, CE, Handbook for Concrete and Cement, with quarterly supplements, Vicksburg, MS, August 1949.

Table 1
Chemical and Physical Properties
Types II and V Cement

Chemical

Constituents	Percent of Composition by Mass Type II	V
SiO_2	21.3	23.6
Al_2O_3	4.5	3.3
Fe_2O_3	2.7	3.2
MgO	3.9	1.9
SO_3	2.6	2.0
Loss on ignition	1.0	1.14
Alkalies - total as Na_2O	0.47	0.49
Na_2O	0.21	0.27
K_2O	0.40	0.33
Insoluble residue	0.18	0.28
CaO	63.5	63.9
C_3S	55	48
C_3A	7.3	3.4
C_2S	20	31
$C_3A + C_3S$	62	51
C_4AF	8.3	9.7
$C_4AF + 2\ C_3A$	22.9	16.6

Physical

Property	Value	
Surface area, sq. cm/g	3420	3490
Air content, %	8.3	9.2
Compressive strength, 3 days, psi	2930	--
Compressive strength, 7 days, psi	3720	2900
Autoclave expansion, %	0.12	0.01
Initial set, hr/min	3.10	4.00
Final set, hr/min	5.25	6.00

Table 2
Chemical and Physical Properties
Class F Fly Ash

Chemical

Constituents	Percent, by Mass
$SiO_2 + Al_2O_3 + Fe_2O_3$	85.1
MgO	1.9
SO_3	1.4
Available Alkalies	0.65
Loss on ignition	2.2

Physical

Property	Value
Pozzolan strength, % control	112
Autoclave Expansion, %	0.01
Moisture Content, %	0.3
Air permeability fineness, sq cm/g	10,460
Lime Pozzolan strength, psi	1380
Water requirement, increase in flow, %	28
Specific gravity	2.62

Table 3

Sieve and Hydrometer and Analyses

Project Soil

Seive	Percent Finer by Mass
No. 10	100
No. 16	99.5
No. 20	98.9
No. 30	97.8
No. 40	95.3
No. 50	89.1
No. 70	72.4
No. 100	54.5
No. 140	36.3
No. 200	20.0
0.055 mm	15.6
0.039 mm	12.7
0.028 mm	11.6
0.0145 mm	10.0
0.0103 mm	9.2
0.0073 mm	8.6
0.0052 mm	7.8
0.0037 mm	6.7
0.0015 mm	5.9

Table 4
Mineralogical Composition of Soil TUL-41 S-1

Constituents	Estimated Amounts*
Nonclays	
Quartz	Intermediate
Mica**	Common
Potassium feldspar	Common
Plagioclase feldspar	Minor
Calcite	Common
Hematite	Minor
Clays	
Kaolinite	Rare
Chlorite	Rare

* The estimated amounts are:

Intermediate	25 to 50 percent
Common	10 to 25 percent
Minor	5 to 10 percent
Rare	less than 5 percent

** This category includes some clay-sized material.

Table 5
Test Results for Chemical Analysis of Soil

Constituent	Percent
SiO_2	77.01
Fe_2O_3	1.93
Al_2O_3	6.78
CaO	5.09
MgO	1.75
Na_2O	0.53
K_2O	1.81
SO_3	<0.01
Cl	<0.01
Ignition Loss 900°C	5.80

Table 6
Chemical Analysis of Truscott City Water

Parameter	Test Results (mg/L)
Calcium	126
Magnesium	34
Sodium	129
Potassium	5.3
Iron	<0.1
Aluminum	<0.5
Silica	5.4
Manganese	<0.01
Sulfate	119
Chloride	143
Bicarbonates	360
Total Alkalinity (as $CaCO_3$)	298
Total Dissolved Solids	887

Table 7
Laboratory Water (Truscott Tap Water)

Constituent	Concentration mg/L
Calcium	132
Chloride	152
Sodium	124
Magnesium	22
Sulfate	122
Bicarbonates	330

Table 8
Ion Concentration (Project Water)

Constituent	Concentration mg/L
Sodium	35,660
Chloride	55,000
Magnesium	1,300
Calcium	1,000
Sulfate	7,540

Table 9
Chemical Analysis of Water from Bateman & North Wichita River
Water as Received, mg/L

	Source	
Constituent	Bateman	North Wichita River
Sodium	8,050	3,560
Potassium	40	18
Chloride	12,410	5,480
Calcium	1,320	820
Magnesium	330	210
Sulfate	2,960	2,370
Total Solids	25,550	12,810

Table 10
Analysis of Concentrated Water, mg/L

	Source	
Constituent	Bateman	North Wichita River
Sodium	37,870	36,170
Chloride	58,400	55,780
Calcium	1,580	980
Magnesium	1,410	1,770
Sulfate	6,240	8,910
Total Solids	108,700	107,510

All results reported in mg/L

Table 11
Optimum Moisture - Maximum Density Values

Type Cement	Cement or Cement Plus Fly Ash %	Fly Ash Added %	Optimum moisture, %	Maximum Density (dry), pcf
II	6	0	11.9	114.8
II	8	0	12.0	114.1
II	10	0	12.0	119.1
II	12	0	11.8	120.5
II	14	0	11.3	119.2
II	16	0	10.8	119.7
II	10	20	11.5	118.9
II	12	20	11.7	118.3
II	14	20	11.4	119.6
II	16	20	11.1	120.7
V	10	0	11.6	118.6
V	12	0	11.3	118.1
V	14	0	11.4	119.2
V	16	0	11.0	120.0
V	10	20	11.4	117.2
V	12	20	11.6	118.4
V	14	20	10.6	119.5
V	16	20	11.5	121.6

Table 12
Compressive Strength
28-Day Cure

Cement %	-y Ash %	28-Day Compressive Strength*, psi Type II	Type V
6	0	345	--
8	0	540	--
10	0	1130	1110
12	0	1460	1570
14	0	2010	1960
16	0	2510	2300
10	20	1080	830
12	20	1340	1240
14	20	1880	1510
16	20	2320	1560

* Average of 3 values.

Table 13
Freezing-Thawing Data 45 Cycles
28-Day Cure

Cement %	Fly Ash %	Specimen Preparation	Percent Loss Type II	Percent Loss Type V
6[3]	0	nb[1]	39.8	--
		b[2]	55.5	--
8[3]	0	nb	3.6	--
		b	24.0	--
10	0	nb	3.1	4.9
		b	13.1	10.5
12	0	nb	1.4	1.8
		b	7.8	4.1
14	0	nb	0.01	1.2
		b	4.4	2.3
16	0	nb	0.01	1.2
		b	2.7	1.2
10	20	nb	4.1	9.9
		b	26.1	18.5
12	20	nb	2.2	3.7
		b	11.1	8.2
14	20	nb	1.0	2.8
		b	6.7	4.3
16	20	nb	3.9	2.4
		b	6.9	2.9

1. nb = not brushed (1 specimen).
2. b = brushed (average of two specimens).
3. 22 cycles only.

Table 14

Standard Wetting-Drying Data 45 Cycles

28-Day Cure

Cement %	Fly Ash %	Specimen Preparation	Percent Loss Type II	Percent Loss Type V
10	0	nb[1]	0.5	
		b[2]	7.8	7.5
12	0	nb	0.3	
		b	3.7	3.5
14	0	nb	0.2	
		b	2.4	1.5
16	0	nb	0.3	
		b	2.3	0.3
10	20	nb	0.7	
		b	19.3	15.5
12	20	nb	0.2	
		b	7.9	6.7
14	20	nb	0.0	
		b	3.9	3.7
16	20	nb	0.2	
		b	2.9	1.5

1. nb = not brushed (1 specimen).
2. b = brushed (average of 2 specimens).

Table 15
Expansion Sulfate Attack Wetting-Drying
45-Day Cure

Type	Cement %	Fly Ash %	Percent Expansion,* Days after 45-Day Cure 1	3	8	14	28	60
II	10	0	0.15	0.26	0.31	0.31	0.26	0.29
II	12	0	0.15	0.27	0.31	0.32	0.27	0.29
II	14	0	0.14	0.28	0.31	0.32	0.29	0.29
II	16	0	0.14	0.29	0.32	0.34	0.29	0.31
II	10	20	0.15	0.25	0.26	0.28	0.26	0.27
II	12	20	0.14	0.27	0.27	0.28	0.26	0.29
II	14	20	0.14	0.28	0.29	0.31	0.29	0.31
II	16	20	0.14	0.28	0.29	0.29	0.28	0.31
V	10	0	0.15	0.24	0.24	0.26	0.25	0.28
V	12	0	0.14	0.25	0.26	0.27	0.26	0.27
V	14	0	0.14	0.25	0.26	0.26	0.27	0.28
V	16	0	0.14	0.25	0.26	0.26	0.27	0.27
V	10	20	0.16	0.25	0.26	0.25	0.26	0.28
V	12	20	0.14	0.23	0.24	0.23	0.27	0.25
V	14	20	0.16	0.26	0.27	0.26	0.29	0.29
V	16	20	0.14	0.25	0.25	0.24	0.28	0.28

* Average of three values.

Table 16
Expansion Sulfate Attack Wetting-Drying
28-Day Cure

Type	Cement %	Fly Ash	Percent Expansion,* Days after 28-Day Cure 7	14	180
II	6	0	0.11	0.13	0.10
II	8	0	0.09	0.12	0.05

* Average of three values

Table 17
Expansion Sulfate Attack Immersed
45-Day Cure

Type	Cement %	Fly Ash %	Percent Expansion,* Days after 45-Day Cure 1	3	8	14	28	180
II	10	0	0.11	0.11	0.14	0.14	0.14	0.20
II	12	0	0.12	0.12	0.15	0.15	0.15	0.20
II	14	0	0.09	0.11	0.12	0.12	0.12	0.19
II	16	0	0.09	0.11	0.12	0.11	0.12	0.16
II	10	20	0.13	0.15	0.17	0.17	0.17	0.22
II	12	20	0.11	0.11	0.14	0.14	0.14	0.17
II	14	20	0.11	0.12	0.14	0.14	0.14	0.19
II	16	20	0.09	0.11	0.12	0.12	0.13	0.16
V	10	0	0.11	0.11	0.13	0.13	0.14	0.19
V	12	0	0.11	0.11	0.13	0.13	0.13	0.17
V	14	0	0.11	0.11	0.12	0.12	0.13	0.16
V	16	0	0.11	0.11	0.13	0.13	0.13	0.16
V	10	20	0.11	0.12	0.14	0.14	0.14	0.19
V	12	20	0.11	0.12	0.13	0.13	0.14	0.18
V	14	20	0.12	0.13	0.15	0.15	0.15	0.18
V	16	20	0.11	0.11	0.13	0.13	0.13	0.16

* Average of three values.

Table 18
Expansion Sulfate Attack Immersed
28-Day Cure

Type	Cement %	Fly Ash %	Percent Expansion,* Days after 28-Day Cure 7	14	180
II	6	0	0.09	0.17	0.17
II	8	0	0.06	0.11	0.17

* Average of three values.

Table 19
Ultrasonic Pulse Velocity Sulfate Attack Wetting-Drying
28-Day Cure

Type	Cement %	Fly Ash %	Ultrasonic Pulse Velocities, Feet per Second: Initial	90 days	180 days
II	10	0	8600	9700	9320
II	12	0	9320	10,420	10,030
II	14	0	9930	10,580	10,570
II	16	0	10,180	10,850	10,070
II	10	20	7430	10,150	9360
II	12	20	8110	10,470	9760
II	14	20	8990	10,470	10,390
II	16	20	9545	11,030	10,880
V	10	0	7580	9470	10,130
V	12	0	8040	9940	10,160
V	14	0	8560	10,370	10,390
V	16	0	9280	10,750	10,000
V	10	20	6350	9420	9260
V	12	20	7040	9600	10,070
V	14	20	8360	10,200	10,450
V	16	20	8700	11,000	9700

Table 20
Ultrasonic Pulse Velocity Sulfate Attack Immersed
28-Day Cure

Type	Cement %	Fly Ash %	Ultrasonic Pulse Velocities, Feet per Second Initial	90 days	180 days
II	10	0	8420	10,150	11,060
II	12	0	9360	10,640	11,440
II	14	0	10,130	11,060	11,720
II	16	0	10,450	11,190	12,000
II	10	20	7790	10,090	11,250
II	12	20	8410	10,590	11,510
II	14	20	8690	11,090	11,720
II	16	20	9970	11,250	12,230
V	10	0	7410	10,150	10,820
V	12	0	8380	10,580	11,440
V	14	0	8900	10,880	11,720
V	16	0	9400	11,120	12,000
V	10	20	6510	9890	10,820
V	12	20	7270	10,250	11,060
V	14	20	8310	10,790	11,520
V	16	20	8670	10,940	11,440

Table 21
Ultrasonic Pulse Velocity
28-Day Cure

Type	Cement %	Fly Ash %	Ultrasonic Pulse Velocities Feet per Second
			Initial
II	6	0	8180
II	8	0	9100

Table 22
Compressive Strength
28-Day Cure + 6-Month Cure

Cement %	Fly Ash %	Compressive Strength*, psi 28 Day + 6 Months Type II	Type V
10	0	2030	2600
12	0	2590	3270
14	0	3620	2910
16	0	4340	3880
10	20	2120	1820
12	20	2670	2240
14	20	3660	2930
16	20	4150	3220

* Average of three values.

Table 23
Freezing-Thawing Data 21 Cycles
28-Day + 6-Month Cure

Cement %	Fly Ash %	Specimen Preparation	Percent Loss Type II	Percent Loss Type V
10	0	nb	4.1	6.4
		b	6.6	4.8
12	0	nb	3.3	3.8
		b	3.5	4.0
14	0	nb	2.8	3.2
		b	2.5	2.9
16	0	nb	2.9	3.1
		b	2.8	2.0
10	20	nb	12.4	7.9
		b	12.1	7.8
12	20	nb	7.7	5.3
		b	6.6	5.7
14	20	nb	6.0	4.7
		b	4.6	4.4
16	20	nb	4.2	4.5
		b	3.1	3.9

Table 24
Standard Wetting-Drying Data 21 Cycles
28-Day + 6-Month Cure

Cement %	Fly Ash %	Specimen Preparation	Percent Change (+ % gain) (- % loss) Type II	Type V
10	0	nb[1]	+1.6	+1.2
		b	+0.4	+0.5
12	0	nb	+1.6	+1.6
		b	+0.9	+0.9
14	0	nb	+1.1	+0.7
		b	+1.2	+1.3
16	0	nb	+0.5	+1.5
		b	+0.8	+0.9
10	20	nb	+0.5	+0.8
		b	-0.8	-0.5
12	20	nb	+0.5	+0.5
		b	-0.1	+0.2
14	20	nb	+0.1	+0.6
		b	-0.4	+0.5
16	20	nb	-0.2	+0.4
		b	+0.2	+0.2

1. nb = not brushed (1 specimen).
2. b = brushed (average of 2 specimens).

Table 25

Expansion Sulfate Attack Wetting-Drying

28-Day + 6-Month Cure

Type	Cement %	Fly Ash %	Percent Expansion* Days after Cure Period 7[1]	14[1]	180[2]
II	10	0	0.07	0.09	0.01
II	12	0	0.07	0.09	0.01
II	14	0	0.08	0.09	0.02
II	16	0	0.08	0.11	0.02
II	10	20	0.10	0.12	0.05
II	12	20	0.08	0.11	0.03
II	14	20	0.09	0.13	0.03
II	16	20	0.09	0.12	0.03
V	10	0	0.06	0.09	0.01
V	12	0	0.06	0.09	0.01
V	14	0	0.07	0.08	0.03
V	16	0	0.06	0.08	0.01
V	10	20	0.07	0.11	0.03
V	12	20	0.07	0.09	0.01
V	14	20	0.09	0.10	0.01
V	16	20	0.07	0.09	0.01

* Average of 3 values.

1. 7- and 14-day readings were made at end of wet cycles.
2. 180-day readings made at end of dry cycle.

Table 26
Expansion Sulfate Attack Immersed
28-Day + 6-Month Cure

Type	Cement %	Fly Ash %	Percent Expansion,* Days after Cure Period 7	14	28	180
II	10	0	0.06	0.06	0.15	0.38
II	12	0	0.06	0.06	0.12	0.35
II	14	0	0.05	0.05	0.11	0.18
II	16	0	0.05	0.03	0.08	0.17
II	10	20	0.08	0.11	0.13	0.43
II	12	20	0.07	0.06	0.11	0.20
II	14	20	0.07	0.06	0.12	0.21
II	16	20	0.09	0.11	0.12	0.20
V	10	0	0.08	0.11	0.08	0.26
V	12	0	0.07	0.05	0.07	0.16
V	14	0	0.07	0.09	0.09	0.11
V	16	0	0.05	0.05	0.07	0.17
V	10	20	0.09	0.07	0.11	0.21
V	12	20	0.08	0.04	0.11	0.19
V	14	20	0.07	0.07	0.09	0.19
V	16	20	0.09	0.04	0.09	0.16

* Average of three values.

Table 27
Ultrasonic Pulse Velocities Undisturbed State
28-Day + 6-Month Cure

Cement %	Fly Ash %	Ultrasonic Pulse Velocities Feet per Second Type II	Type V
10	0	9390	10,100
12	0	9800	10,360
14	0	11,060	11,390
16	0	11,900	11,110
10	20	9130	9520
12	20	11,300	10,260
14	20	10,930	11,110
16	20	11,060	10,930

Table 28
Compressive Strength 7-Day + 24-Hr Curve

Cement	Fly Ash	Compressive Strength,* psi Type II	Type V
10	0	740	830
12	0	1130	940
14	0	1390	1320
16	0	1550	1600
10	20	730	600
12	20	880	880
14	20	1170	1090
16	20	1450	1340

* Average of three values.

Table 29

Freeze-Thawing Data 15 Cycles 7-Day + 24-Hr Cure

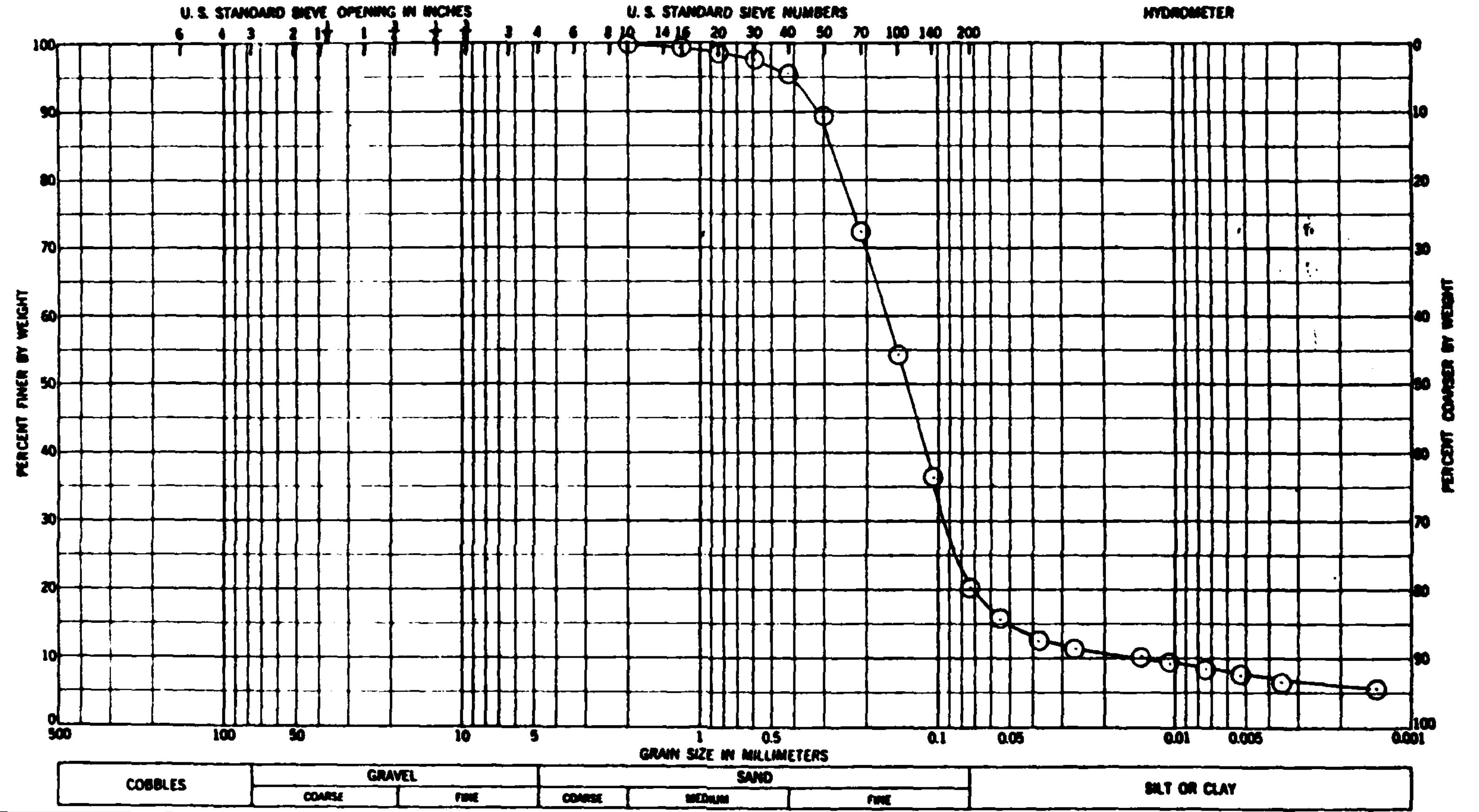
Cement	Fly Ash	Specimen Preparation	Percent Loss Type II	Type V
10	0	nb[1]	4.2	3.0
		b[2]	13.6	14.3
12	0	nb	2.7	5.2
		b	6.3	10.3
14	0	nb	0.8	6.8
		b	4.5	7.0
16	0	nb	0.6	1.1
		b	2.8	4.5
10	20	nb	7.5	2.3
		b	17.4	19.8
12	20	nb	5.0	5.6
		b	10.2	12.8
14	20	nb	2.4	3.0
		b	7.1	9.1
16	20	nb	2.0	2.6
		b	5.2	7.2

[1] nb = not brushed (1 specimen).
[2] b = brushed (average of 2 specimens).

Table 30

Standard Wetting-Drying Data 14 Cycles 7-Day + 24-Hr Cure

Cement	Fly Ash	Specimen Preparation	Percent Loss Type II	Percent Loss Type V
10	0	nb	6.0	6.8
		b	8.5	8.9
12	0	nb	5.8	5.9
		b	6.9	7.1
14	0	nb	5.7	5.9
		b	6.1	6.4
16	0	nb	5.5	5.9
		b	5.9	6.0
10	20	nb	6.7	6.9
		b	10.3	10.9
12	20	nb	6.1	6.1
		b	8.0	8.0
14	20	nb	5.5	5.6
		b	6.7	6.7
16	20	nb	5.6	5.5
		b	6.1	6.1



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
		SILTY SAND(SM) REDDISH BROWN Gs= 2.66(est)		NP		

Project

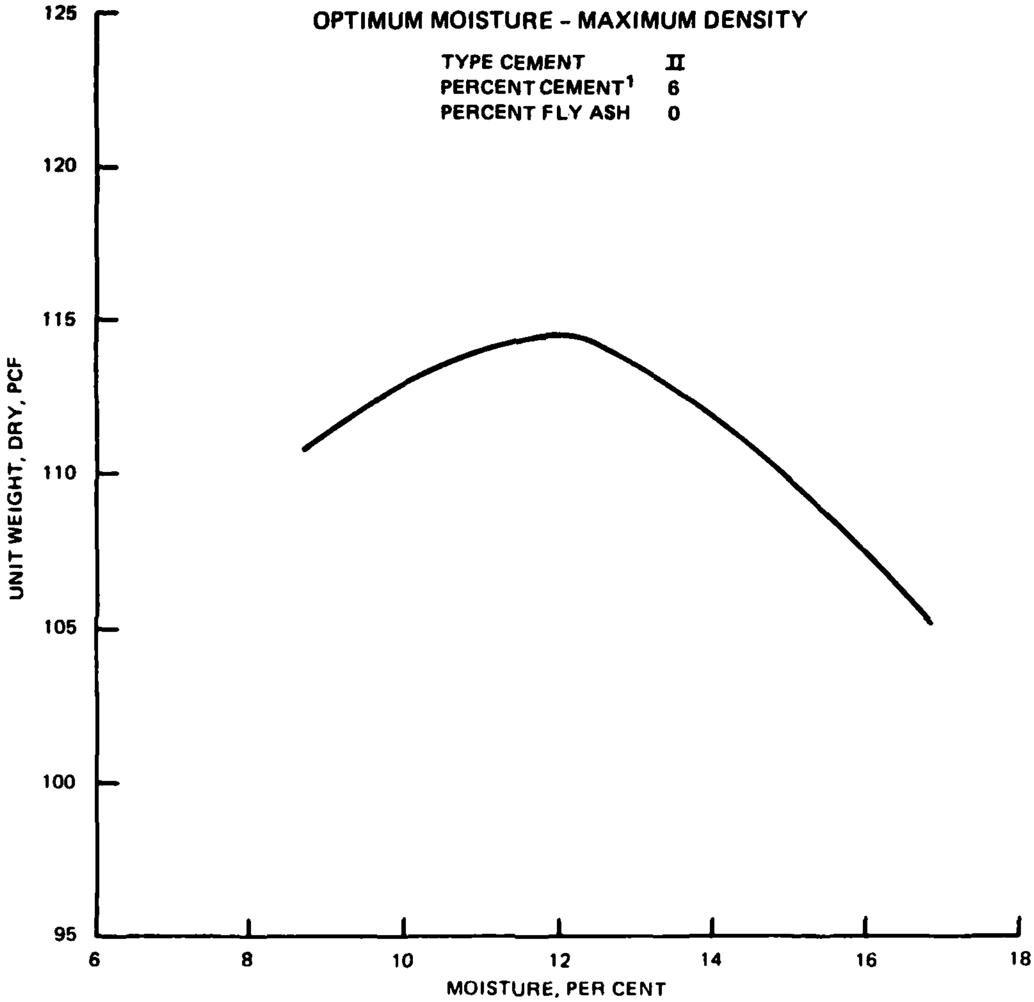
Area

Boring No. JOB NO. 441-C690.18CC31

Date 2 MAY 78

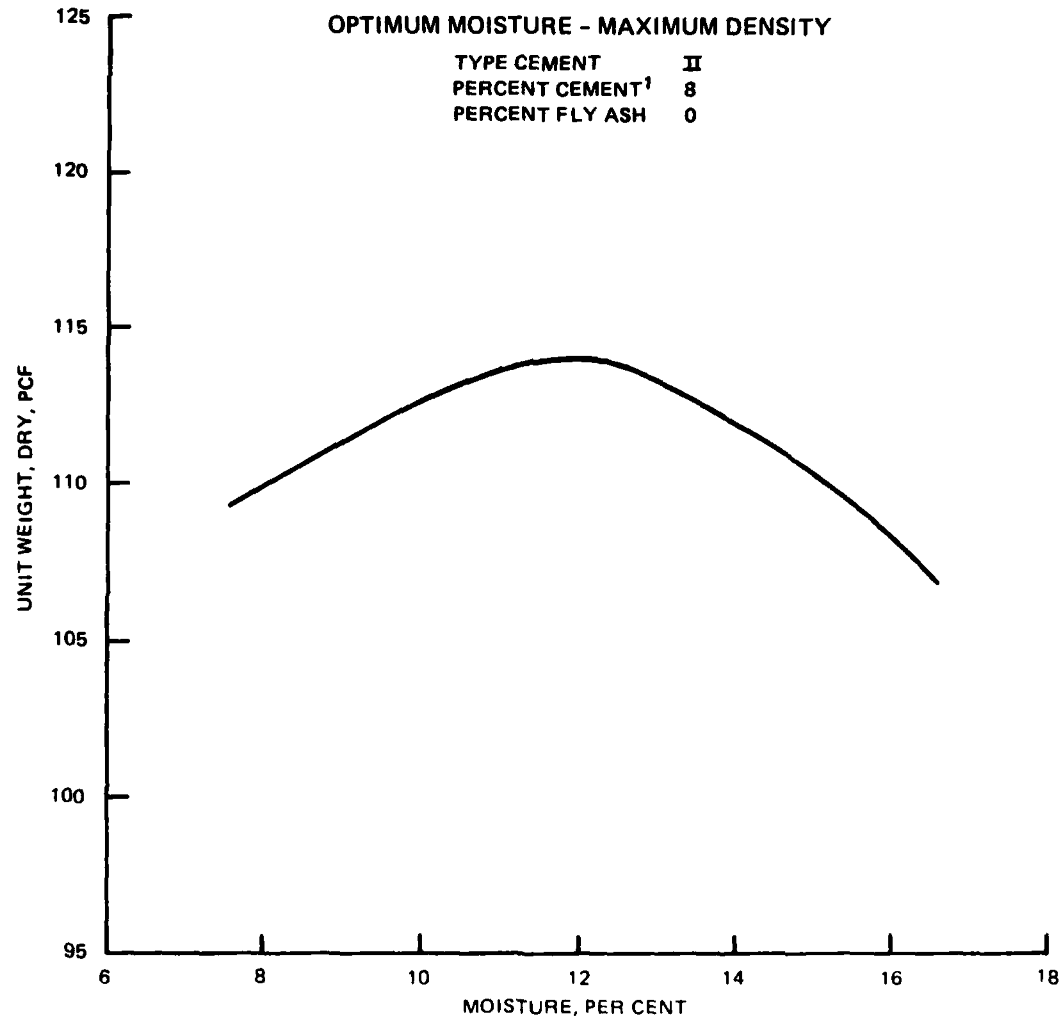
GRADATION CURVES

Figure 1



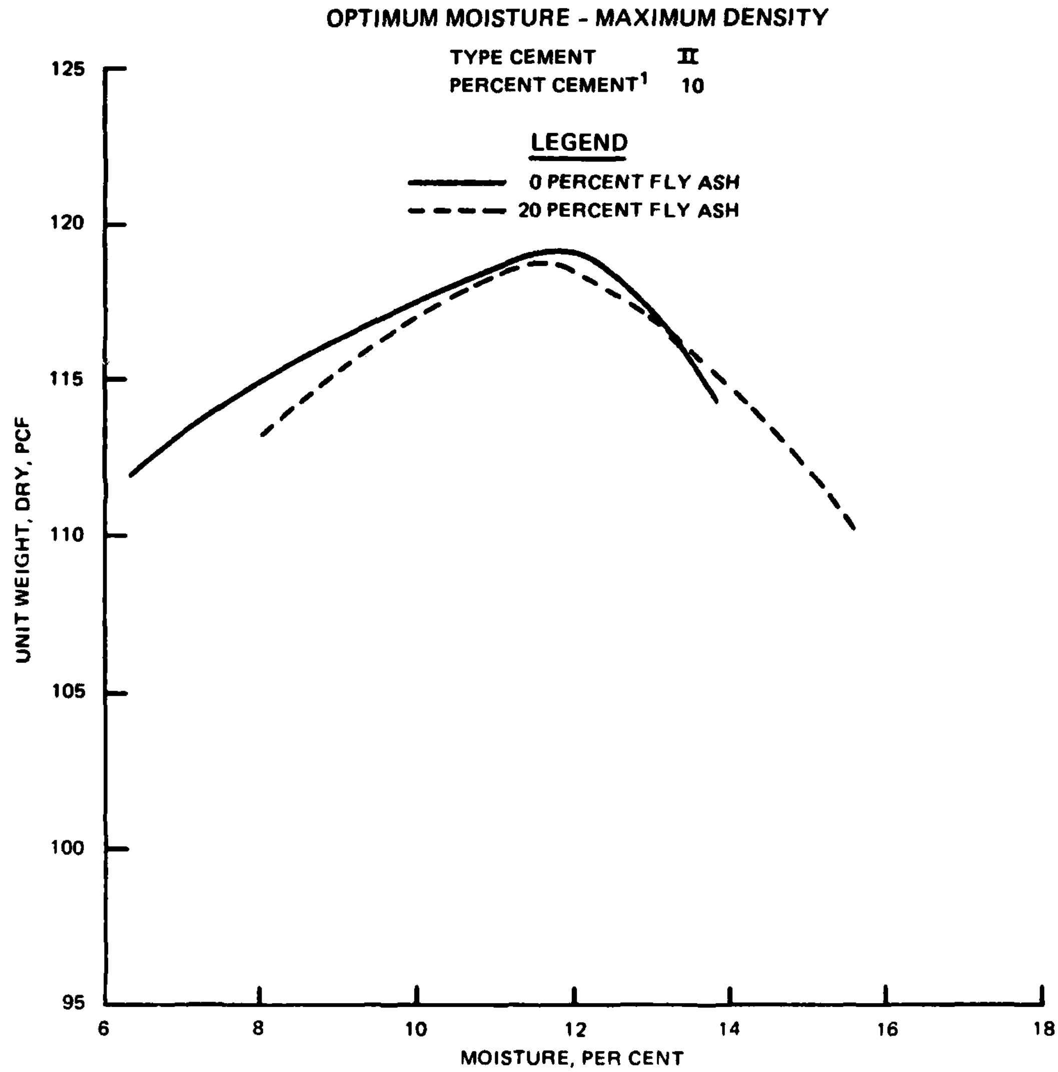
NOTE: THIS IS PERCENT CEMENTITIOUS MATERIAL
IF MIXTURE CONTAINS FLY ASH

Figure 2



NOTE: THIS IS PERCENT CEMENTITIOUS MATERIAL IF MIXTURE CONTAINS FLY ASH

Figure 3



NOTE: THIS IS PERCENT CEMENTITIOUS MATERIAL
IF MIXTURE CONTAINS FLY ASH

Figure 4

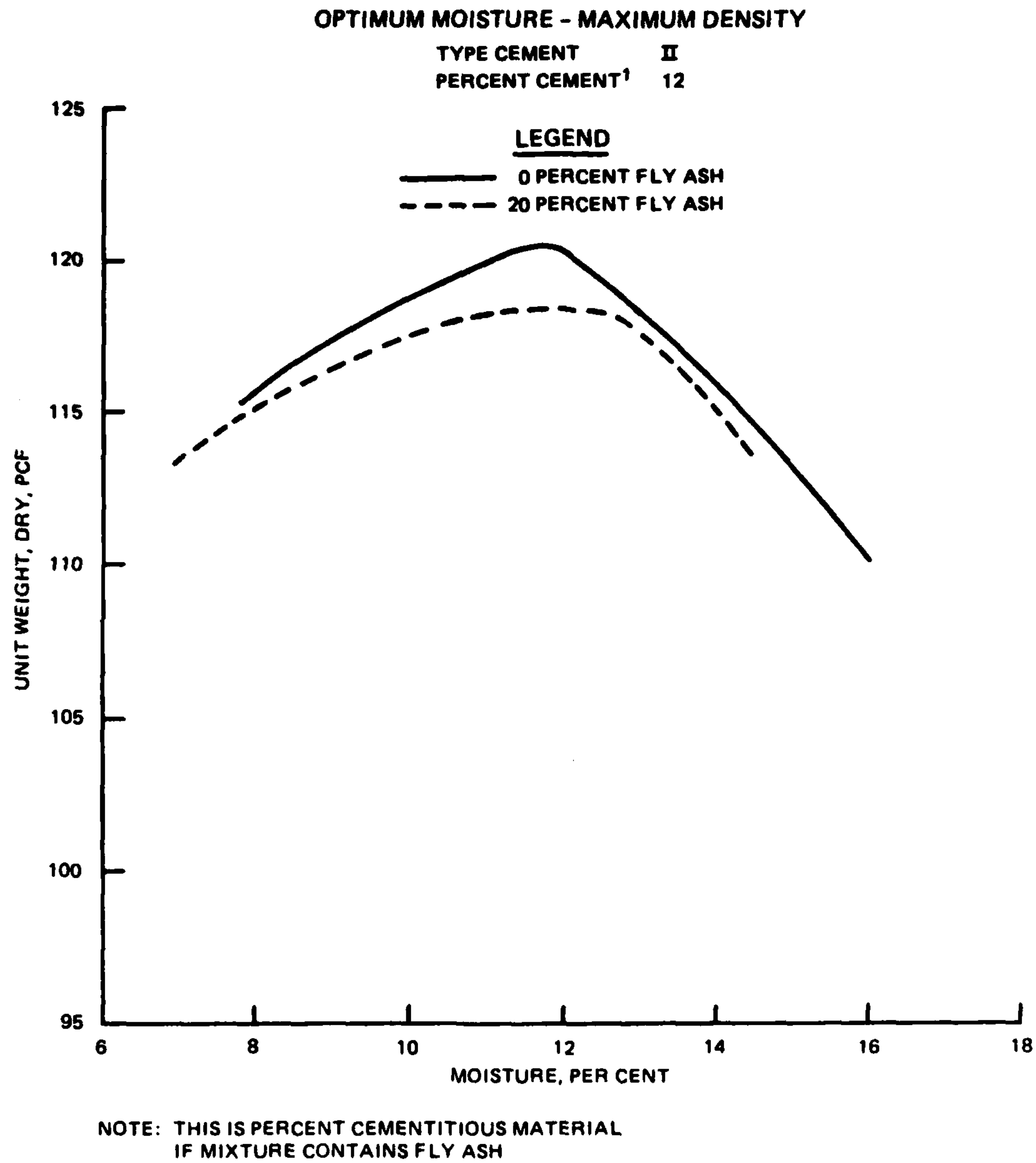
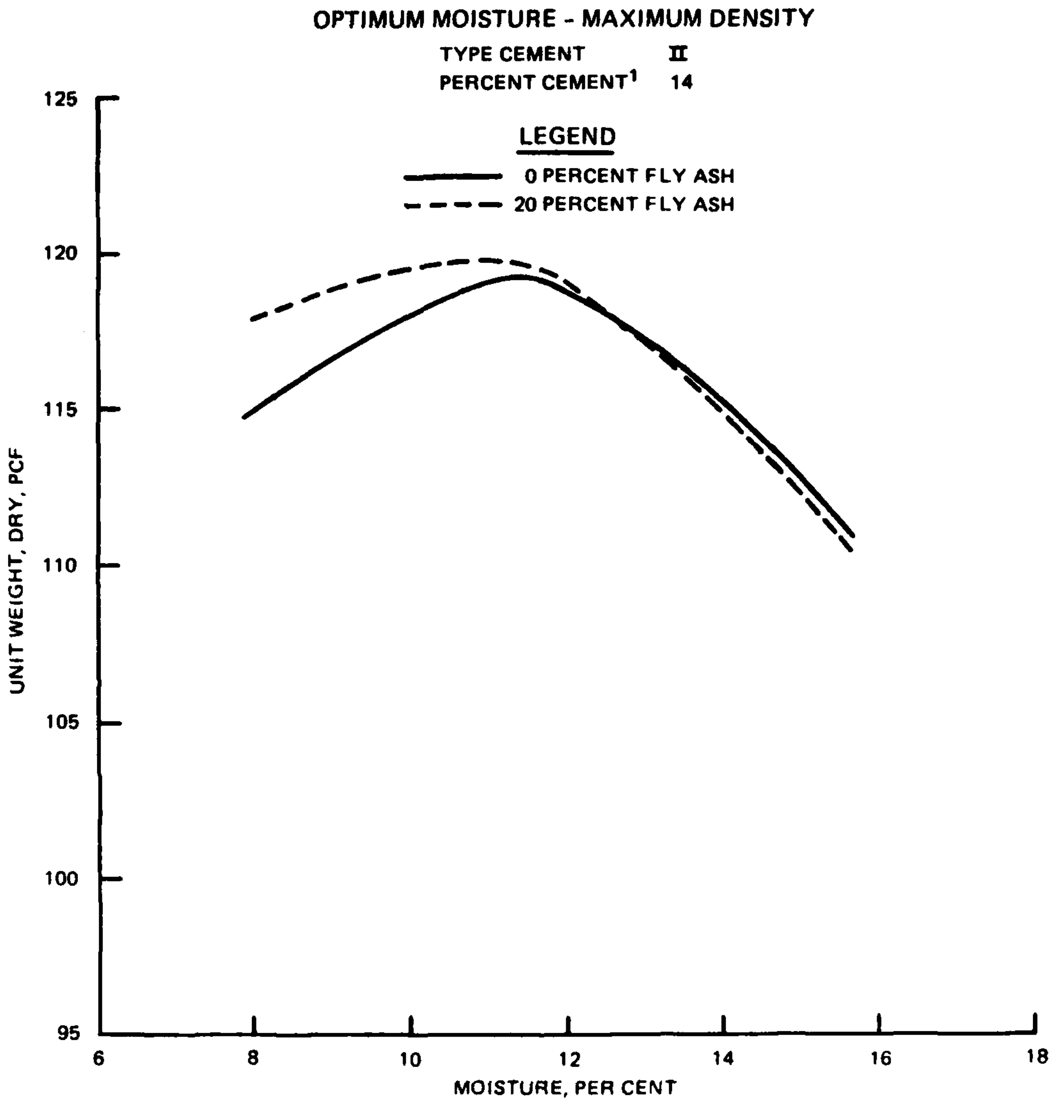
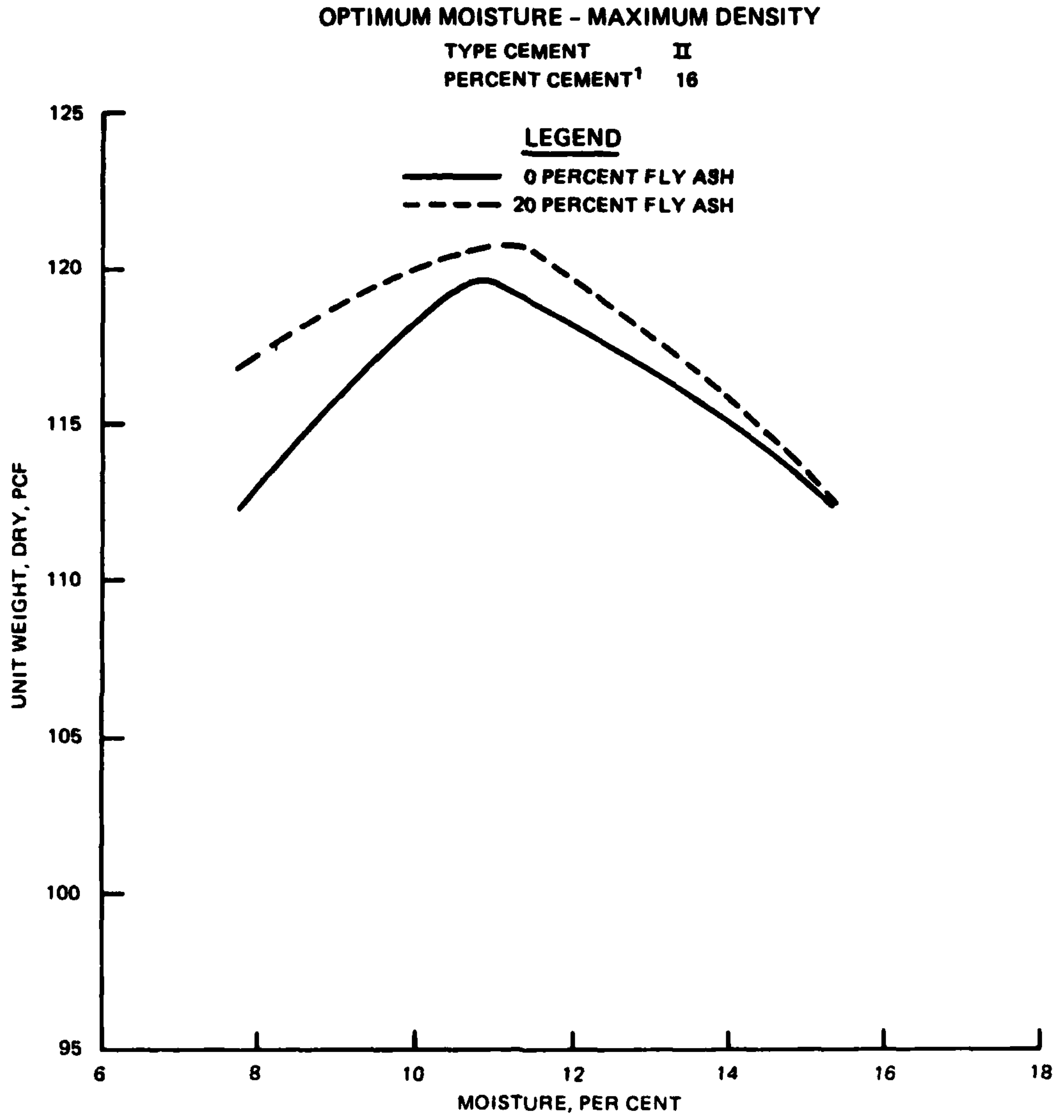

OPTIMUM MOISTURE - MAXIMUM DENSITY
TYPE CEMENT II
PERCENT CEMENT[1] 12
LEGEND
0 PERCENT FLY ASH
20 PERCENT FLY ASH
125
120
115
110
105
100
95
UNIT WEIGHT, DRY, PCF
6
8
10
12
14
16
18
MOISTURE, PER CENT
NOTE: THIS IS PERCENT CEMENTITIOUS MATERIAL
IF MIXTURE CONTAINS FLY ASH

Figure 5



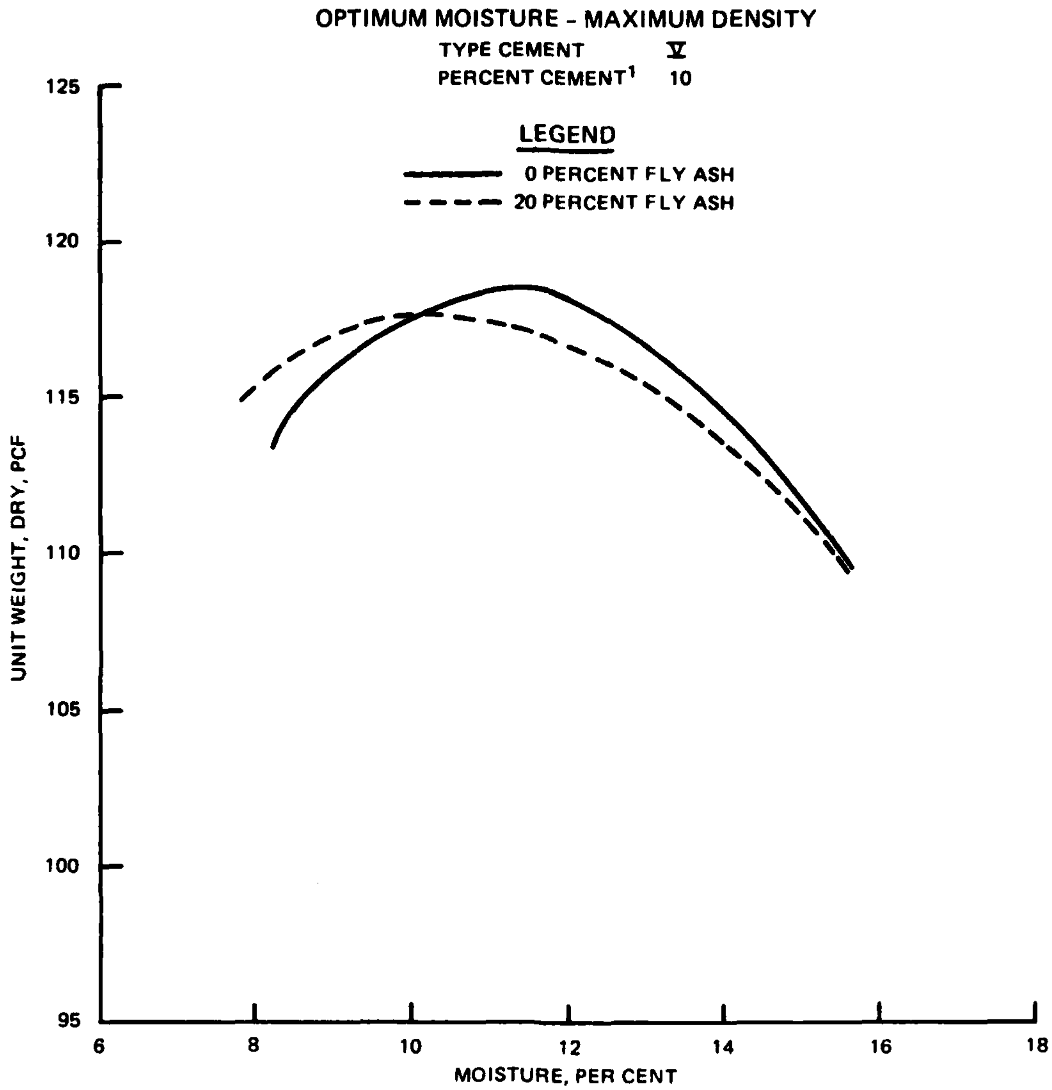
NOTE: THIS IS PERCENT CEMENTITIOUS MATERIAL
IF MIXTURE CONTAINS FLY ASH

Figure 6



NOTE: THIS IS PERCENT CEMENTITIOUS MATERIAL
IF MIXTURE CONTAINS FLY ASH

Figure 7



NOTE: THIS IS PERCENT CEMENTITIOUS MATERIAL
IF MIXTURE CONTAINS FLY ASH

Figure 8

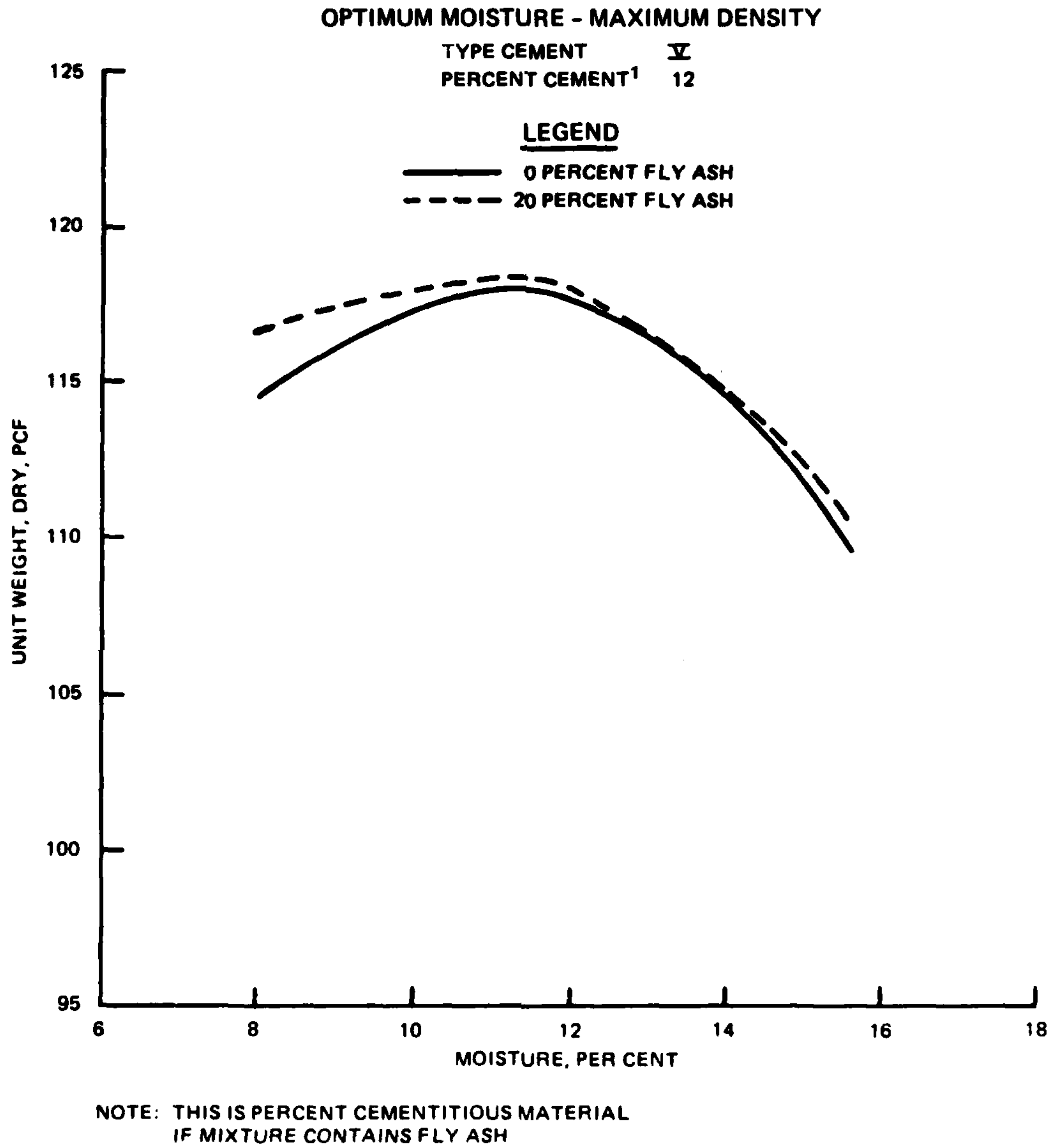
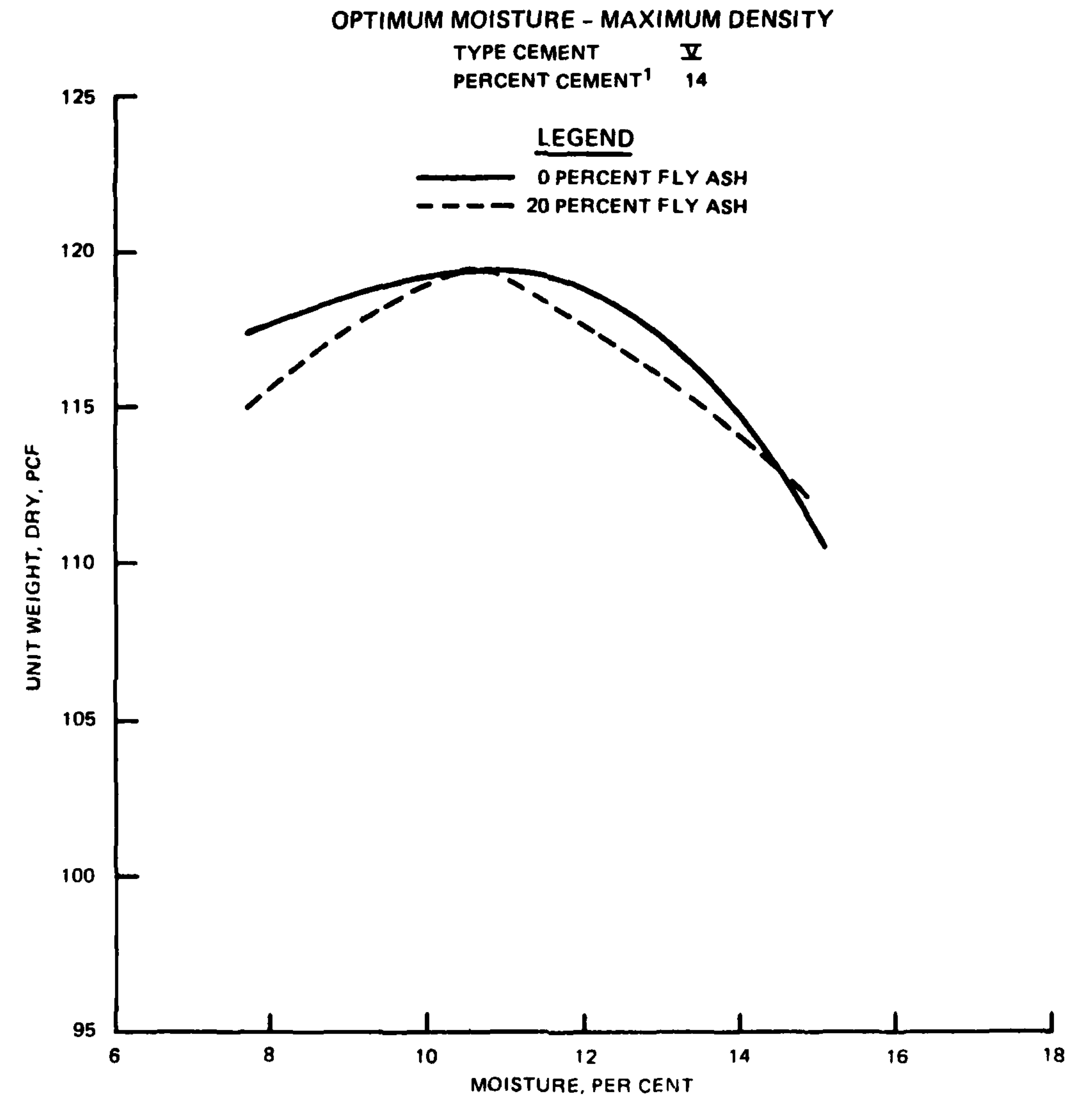
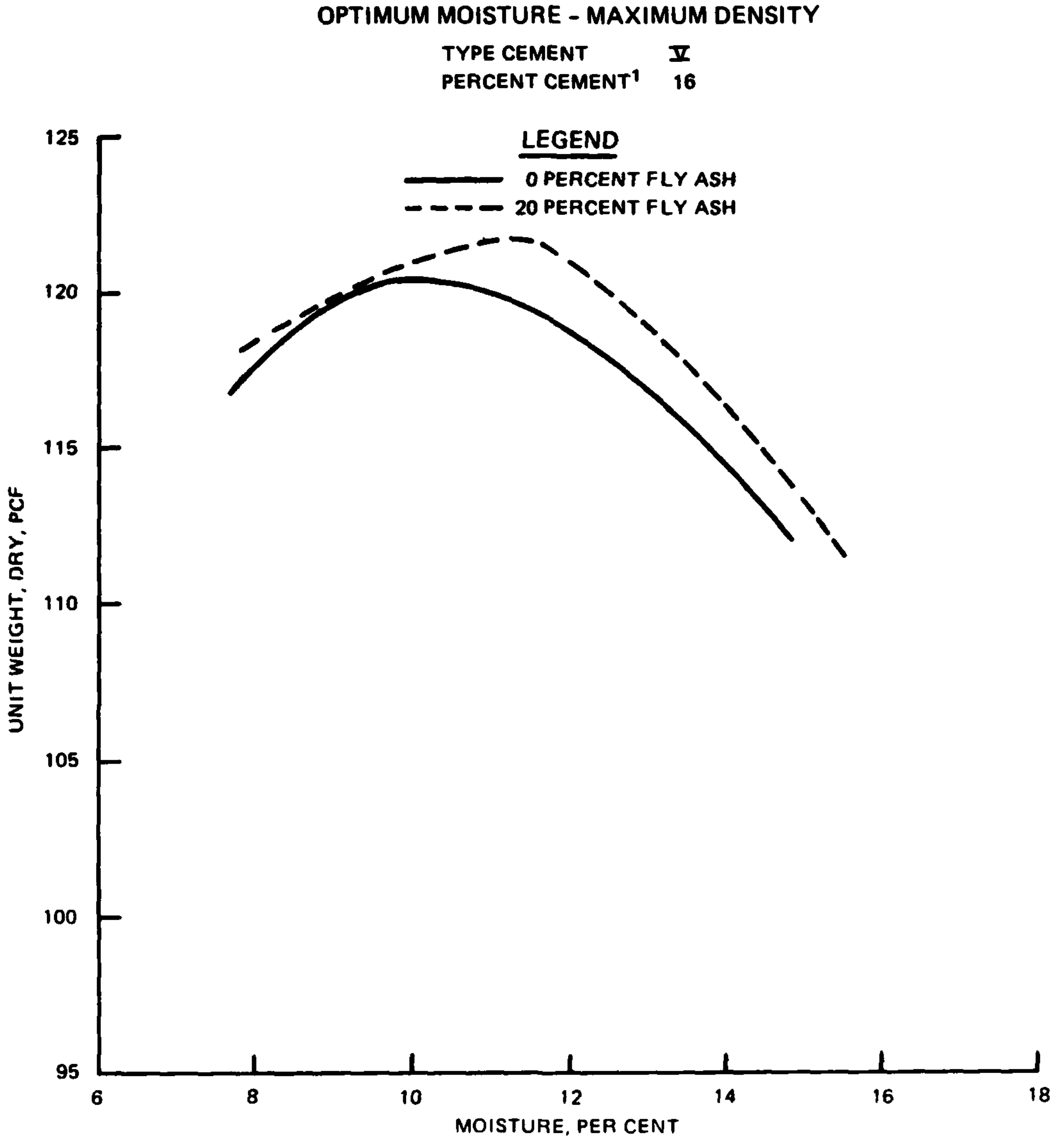

OPTIMUM MOISTURE - MAXIMUM DENSITY
TYPE CEMENT V
PERCENT CEMENT[1] 12
LEGEND
0 PERCENT FLY ASH
20 PERCENT FLY ASH
125
120
115
110
105
100
95
UNIT WEIGHT, DRY, PCF
6
8
10
12
14
16
18
MOISTURE, PER CENT
NOTE: THIS IS PERCENT CEMENTITIOUS MATERIAL
IF MIXTURE CONTAINS FLY ASH

Figure 9



NOTE: THIS IS PERCENT CEMENTITIOUS MATERIAL
IF MIXTURE CONTAINS FLY ASH

Figure 10



NOTE: THIS IS PERCENT CEMENTITIOUS MATERIAL
IF MIXTURE CONTAINS FLY ASH

Figure 11

END
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DTIC